

The Federal Government is the largest single user of energy in the United States and purchases an estimated \$10-20 billion in energy-related products. In Federal buildings, annual energy costs are approximately \$1.23 per square foot. The Energy Policy Act of 1992 and Executive Order 12902 set goals for energy reduction and provide some guidelines for implementing conservation measures. FEMP provides information on technologies that have been proven in field testing or recommended by reliable sources, such as the DOE National Laboratories.

Action Moment

The time for planning, evaluating, and implementing is now! Facility managers should first implement energy- and demand-reducing measures in their operations and then look for opportunities to cost-effectively replace conventional technologies with ones using renewable energy sources.

Facility managers should also set goals for their operations that follow Federal mandates. Executive Order 12902 requires an energy reduction in Federal buildings of 30% from 1985 levels by the year 2005. In addition, where possible, facility managers are required to install all energy and water conservation measures with payback periods of less than 10 years. When energy-using equipment needs replacement, guidance for purchasing products that meet or exceed Executive Order 12902 procurement goals is available through FEMP's Product Energy Efficiency Recommendations series.



Technical Information

The Energy Systems and Conservation section of this guide describes systems that provide key opportunities for energy savings. The following are some of these opportunities:

1 HVAC systems improvements offer the greatest potential for energy savings in most facilities. Opportunities include replacing equipment



Photovoltaic panels, such as these powering an irrigation system, can displace electricity purchased from a utility.

with more efficient models, improving controls, upgrading maintenance programs, and retrofitting existing equipment to operate more efficiently. Central plants contain many interrelated components, and upgrading them takes careful planning, professional design assistance, and careful implementation. This guide covers chillers, boilers, steam traps, variable-air-volume systems, and other HVAC technologies.

2 Electric motor systems that operate continuously or for many hours a year consume electricity that costs many times the price of the motor. This makes inefficient, large horsepower motors excellent targets for replacement. If the driven load operates at reduced speed for a majority of the time, installing electronic motor controls would both reduce energy consumption and save operating costs.

3 Lighting. \$250 million could be saved annually if all Federal facilities upgraded to energy-efficient lighting. Light energy savings of up to 40% can be achieved in interior applications by replacing lamps and ballasts. Savings of 80% are possible by designing and implementing an integrated approach to lighting system retrofits.

4 **Electrical power systems** can be made more efficient through (1) maintenance practices focused on identifying potential trouble areas such as loose electrical connections, and (2) selection of efficient equipment, such as transformers.

5 **Office equipment** is becoming an ever greater proportion of building loads. “Green” appliances that feature automatic power shutdown and more efficient electronics can help reduce energy consumption.

6 **Water heating** is a major fuel consumer in facilities with kitchens and laundries. Beyond reducing the use of hot water, various heat recovery and solar technologies can help reduce operating cost.

7 **Energy Management and Control Systems (EMCSs)** are critical in avoiding energy waste and monitoring energy consumption. Control technology should be applied intelligently for each situation, and an optimized mix of local and central control should be used.

8 **Building shells** are the physical barrier controlling external heat gain and heat loss. The best opportunities for energy efficiency are in facility design, building orientation and configuration; fenestration; and envelope design. These have substantial impact on building performance. There are many retrofit strategies that can improve the energy efficiency of existing buildings. Window and door treatments can minimize energy transmission through the shell. Understanding the local microclimate can help facility managers take advantage of passive measures.



Energy Savings Performance Contracts (ESPCs) provide Federal agencies a means of increasing the investment in energy saving technologies. With appropriated funds shrinking for many agencies, ESPCs provide a means for agencies to secure financing from Energy Service Contractors

(ESCOs) for identifying and implementing energy conservation measures. In effect, agencies can defer the initial costs of equipment and pay for equipment via the utility bill savings. FEMP assists Federal agencies with ESPCs.

Super ESPCs are a broadened form of ESPC. They are a type of regional agreement where delivery orders are placed against a contract with selected ESCOs. The Super ESPC allows individual facilities to negotiate contracts directly with the selected companies, greatly reducing the complexity of the ESPC process.

Basic Ordering Agreements (BOAs) are written understandings negotiated between GSA and a utility or other business, that set contract guidelines for energy-consuming products and services. For example, the GSA Chet Holifield Federal Center in Laguna Niguel, CA contracted with their electric utility for thermal energy storage, energy-efficient chillers, variable-frequency drives, efficient motors, and lighting system retrofits. The contractor invested \$3,800,000, and the government's share of the savings is \$1,400,000 over 14 years. The GSA retains the equipment after the contract term. One prominent BOA specifying energy-efficient chillers for Federal procurement has been developed between GSA and the five major chiller manufacturers in the United States. Other BOAs are being developed and will be available soon. See section 9.4 for additional information on ESPC, Super ESPC, and BOA programs.

References

Department of Energy, *Architect's and Engineer's Guide to Energy Conservation in Existing Buildings*, (DOE/RL/018-30P-H4), Washington, DC, 1990.

Contacts

For FEMP's *Product Energy-Efficient Recommendations* series or for more information on financing alternatives, visit the FEMP Home Page at <http://www.eren.doe.gov/femp> or call the FEMP Help Desk at (800) DOE-EREC.

Heating, ventilating, and air conditioning (HVAC) systems can be the largest energy consumers in Federal buildings. HVAC systems provide heating, cooling, humidity control, filtration, fresh air makeup, building pressure control, and comfort control, all with infrequent interaction between the occupants and the system. Properly designed, installed, and maintained HVAC systems are efficient, provide comfort to the occupants, and inhibit the growth of molds and fungi. Well-designed, and efficient HVAC systems are essential for Federal buildings and employee productivity. Boilers, steam traps, variable-air-volume systems, chillers, and new HVAC technologies are covered in the following sections.

Action Moment

Consider upgrading or replacing existing HVAC systems with more efficient ones: if current equipment is old and inefficient; if loads have changed due to other conservation measures or changes in building occupancy; if control is poor; if implementing new ventilation standards has caused capacity problems; or, if moisture or other indoor air quality problems exist. Be sure to have a plan in place for equipment change-out and failure. The phaseout of chlorinated fluorocarbons (CFCs) presents an added factor encouraging chiller replacement.



Technical Information

Some common opportunities for reducing HVAC operating costs in large facilities are:

1 Reduce HVAC loads. By reducing building loads, less heating and cooling energy is expended. Load reduction measures include: adding insulation; shading harsh wind and sun exposures with trees, shadescreens, awnings, or window treatments minimizing use of heat-producing equipment, such as office equipment and computers; daylighting; controlling interior lighting; and capturing heat from exhaust air.

2 Incorporate building automation/control systems. These systems can be added or upgraded



Cooling towers, which are usually components of large HVAC systems, can be made more efficient by controlling their operation times and by retrofitting their motors with variable frequency drives.

to improve the overall performance of the building, including the HVAC equipment. Perhaps the simplest measure and the first to be considered is to ensure that HVAC systems are in "setback" mode during unoccupied periods. Existing control systems will often accommodate this very simple measure. Section 3.8 discusses these systems in more detail.

3 Optimize for part-load conditions. Buildings usually operate under conditions where the full heating or air conditioning capacity is not required. Therefore, the greatest overall annual efficiency improvements will result from giving special consideration to part-load conditions. Staging multiple chillers or boilers to meet varying demand greatly improves efficiencies at low and moderate building loads. Pairing different-sized chillers and boilers in parallel offers greater flexibility to central plant equipment. Units should be staged with microprocessor controls to optimize system performance.

4 Isolate off-line chillers and boilers. In parallel systems, off-line equipment should be isolated from cooling towers and distribution loops. With

reduced pumping needs, circulation pumps can be shut off or modulated with variable speed drives.

5 Use economizers. In climates with seasons having moderate temperatures and humidity, adding economizer capabilities can be cost effective. When ambient conditions are suitable, outside air provides space conditioning without the use of the cooling plant. To prevent inappropriate introduction of outside air, economizer logic, controls, and maintenance need careful attention.

6 Ventilation systems in buildings have tremendous impacts on energy use due to the high costs associated with heating or cooling outside air. Buildings should be ventilated according to ASHRAE Standard 62. The elevated outside air introduction requirements (15-20 cfm in most commercial buildings) of Standard 62's most recent version (62-1989) do not apply to buildings constructed before its publication, although for new additions of 25% or more, this "grandfathering" is not permitted by the major building codes. The indoor air quality benefits of complying with ASHRAE 62-1989, such as higher productivity and decreased sick-leave, may often deem the added expense worthwhile, even when not required by law.

7 Upgrade cooling towers. Large savings are possible by retrofitting cooling towers with new fill, efficient transmissions, high-efficiency motors, and variable frequency drives. Good water chemistry is critical to minimize the use of environmentally hazardous chemical biocides. Ozone treatments also may be useful.



Importance of Maintenance

Proper maintenance prevents: loss of HVAC air balance (return, supply, and outdoor air); poor indoor air quality; poor refrigerant charge; fouling of evaporator coils by dust and debris; poor water quality in cooling towers; and, water damage from condensate.

1 Air handler maintenance. To achieve better indoor air quality and reduce operating costs, steam clean evaporator coils and air handlers on a minimum three-year rotation. Also, filters should be changed frequently.

2 Ventilation. A good balance report is required. Air flows can then be periodically checked. Periodically lubricate dampers and check their operation by manually operating them.

3 Air distribution system leakage. In residential and small commercial buildings, air duct leakage can be a huge energy waster. Leaks in return duct systems also cause energy, comfort, and air quality problems. Check ventilation rates after duct repair to ensure that ASHRAE Standards are met and that building zones are not unintentionally depressurized.

4 Improper refrigerant charge. Direct expansion refrigerant systems require precise levels of refrigerant to operate at peak capacity and efficiency, and to best control interior humidity in moist climates. The most common causes of improper refrigerant charge are: failure to use nitrogen- purging when soldering; failure to evacuate lines and coils using recommended methods; failure to leak-test before charging; and failure to use properly calibrated gauges.

5 When upgrading or replacing equipment, ease of maintenance and indoor air quality are important considerations. Consider specifying protection for air handler insulation to prolong effectiveness, filter doors with easy-opening mechanisms, high quality grilles and diffusers, diagnostic capabilities, and appropriate humidity removal. For air distribution system design, use computer-modeled duct design, proper duct- sealing materials and techniques, ducts with smooth interiors, and low-face-velocity coils.

References

American Society of Heating, Refrigerating and Air Conditioning Engineers, *ASHRAE Standard 62*.

Contacts

HVAC retrofits and maintenance opportunities are thoroughly covered in the FEMP-sponsored "Trained Energy Manager" course. Contact the FEMP Help Desk at (800) DOE-EREC.

For written material and software to assist with evaluating HVAC systems, contact the EPA Energy Star Building Hotline at (202) 775-6650.

Most medium-to-large facilities use boilers to generate hot water or steam for space heating, food preparation, and industrial processes. For boilers to run at peak efficiency, operators must attend to water chemistry, pumping and boiler controls, boiler and pipe insulation, fuel-air mixtures, burn-to-load ratio, and stack temperatures.

Action Moment

Every effort should be made to upgrade boiler systems to peak efficiency to reduce operating costs and environmental impacts. When replacing old equipment or installing new equipment, consider the advantages that multiple boiler systems offer. Multiple boiler systems are more efficient than single boilers, especially under part-load conditions. Also, consider solar-assisted systems or biomass-fired boilers in place of conventional boiler systems.



Technical Information

Recent trends in boiler systems include: installing multiple small boiler units; lowering system pressures; decentralizing systems; and installing direct digital control (DDC) systems. Boilers that have efficiencies over 90% are available. Because these systems capture the latent heat of vaporization from combustion water vapor, flue gas temperatures are low enough to vent the exhaust through PVC pipes. PVC resists the corrosive action of flue gas condensate.

1 Add radiator controls. Radiators that operate at full output are common in older office buildings. Adding thermostatic valves that control hot water or steam output to each radiator enables occupants to maintain comfort without opening windows in the winter. In some situations, adding radiator controls can cut steam or hot water use by one-third.

2 Replace inefficient boilers. In newer units, more fuel energy goes into creating steam, so both stack temperatures and excess oxygen are lower.

Estimate efficiencies of existing units by measuring excess air, flue and boiler room temperatures, and percent of flue gas oxygen and carbon dioxide. Some utilities will provide this service free of charge.

3 Decentralize systems. Several smaller units strategically located around a large facility reduce distribution losses and offer flexibility in meeting the demands of differing schedules, and steam pressure and heating requirements. Estimate standby losses by monitoring fuel consumption during no-load periods.

4 Downsize. Strive to lower overall heating demands through prudent application of energy conservation measures. Smaller boilers may be staged to meet loads less expensively than large central plants. Many new units are designed to ease retrofit by fitting through standard doorways.

5 Modernize boiler controls. Direct digital controls (DDC) consist of computers, sensors, and software.

DDCs allow logic-intense functions such as optimizing fuel/air mixture based on continuous flue gas sampling, managing combustion, controlling feedwater and drum levels, and controlling steam header pressure.

6 Install an economizer. Install a heat exchanger in the flue to preheat the boiler feedwater. Efficiency increases about 1% for every 5.5°C (10°F) increase in feedwater temperature. If considering an economizer, ensure: (1) that the stack temperature remains higher than the acid dew point in order to prevent flue damage; and (2) that excess flue temperature is due to insufficient heat transfer surfaces in the boiler rather than scaling or other maintenance problems.

7 Install oxygen trim system. To optimize fuel/air ratio, these systems monitor excess oxygen in the flue gas and modulate air intake to the burners accordingly.

8 **Install automatic flue dampers** to reduce the amount of boiler heat that is stripped away by natural convection in the flue after the boiler cycles off.

9 **Retrofit gas pilots** with electronic ignition systems that are readily available.

10 **Install air pre-heaters** that deliver warm air to the boiler air inlets through ducts. The source of warm air can be the boiler room ceiling, solar panels, or solar-preheat walls. Managers should check with boiler manufacturers to ensure that alterations will not adversely alter the performance, void the warranty, or create a hazardous situation.

11 **Add automatic blowdown controls.** Uncontrolled, continuous blowdown is very wasteful. A 10% blowdown on a 200 psia steam system results in a 3% efficiency loss. Add automatic blowdown controls that sense and respond to boiler water conductivity and pH.

12 **Add a waste heat recovery system to blowdowns.** By capturing blowdown in recovery tanks and using heat exchangers to preheat boiler feedwater, system efficiency can be improved by about 1%.

13 **Consider retrofitting boiler fire tubes with turbulators** for greater heat exchange, after checking with your boiler manufacturer. Turbulators are baffles placed in boiler tubes to increase turbulence, thereby extracting more heat from flue gases.

14 **Detect and repair steam leaks.** Leaks in underground distribution pipes can go undetected for years. Monitor blowdown and feedwater to help detect these leaks.

15 **Reduce excess air to boiler combustion.** The common practice of using 50% to 100% excess air decreases efficiency by 5%. Work with the manufacturer to determine the appropriate fuel/air mixture.

16 **Insulate boiler and boiler piping.** Reduce heat loss through boiler walls and piping by repairing or adding insulation. The addition of 2.5cm (1 inch) of insulation can reduce heat loss by 80% to 90%.



Proper operation and maintenance is the key to efficient boiler operation. Any large boiler plant should maintain logs on boiler conditions as a diagnostic tool. When performance declines, corrective action should be taken.

Reduce soot and scale. Deposits act as insulation on heat exchangers and allow heat to escape up the flue. If the stack temperature rises over time under the same load and fuel/air mixture, and deposits are discovered, adjust and improve water chemistry and fuel/air mixture accordingly. Periodically running the system lean can remove soot.



On systems operating with negative pressure, air may enter the system after the combustion process and give false indications of excess air measured with flue gas oxygen.

References

Brecher, Mark L., "Low-Pressure System Gets High Marks from College," *Heating/Piping/Air Conditioning*, Sept 1994.

Payne, William, *Efficient Boiler Operations Sourcebook*, 3rd Ed., Fairmont Press, 1991.

Washington State Energy Office, Boiler Efficiency Operations, (WAOENG-89-24), Olympia, WA, 1989.

Steam traps are components of steam systems that vent air and drain condensate formed in steam distribution systems, and prevent live steam from exiting when condensate lines are vented. Condensate formed after the steam releases its latent heat of vaporization must be removed to prevent interference with steam flow. Condensate is usually returned to the boiler where heating it again re-creates steam. Steam traps are subject to extremely harsh conditions, and there are no cure-all solutions for steam trap failure. The traditional recommendations of proper sizing, selection, installation and maintenance still apply.

Action Moment

Proactive steam trap maintenance is critical in using steam efficiently. Facility managers should ensure that all facilities using steam follow good maintenance procedures. Establish an effective preventive maintenance program. Determine the optimum maintenance schedule for each trap and follow it. The table on the next page lists conditions that may indicate a failed steam trap.



Technical Information

Developments over the years have led to steam traps that better distinguish between steam and liquid. Conventional traps fit one of three categories: mechanical, thermostatic, or thermodynamic. Each type of trap has a different application.

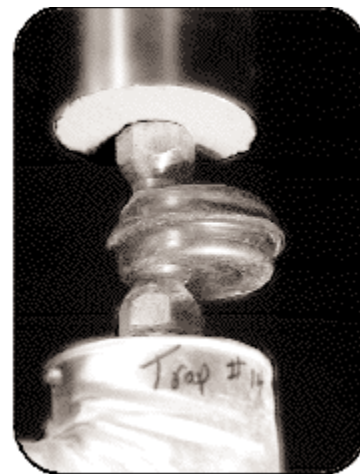
Most traps are designed to fail in the open position in order to protect the steam generation process. However, at failure, the trap dumps live steam continuously to the condensate return. This return line pressure can cause other traps to fail in a cascading manner.

In a single day, steam loss can cost more than the trap and labor required to replace it. As shown in the table, the annual cost of a single failed trap with a 1 cm (3/8") orifice in a 690 kPa (100 psi) system where steam cost is \$15 per 375kg (1000 lbs) is \$57,000. References, such as *Steam Efficiency Improvement*, list leak rates at specific pressures and orifice diameters.

1 Avoid fixed-orifice traps.

Fixed-orifice traps continually blow off live steam and have no way to compensate for variable rates of condensation.

Traps subject to freezing temperatures may be damaged by water held inside the trap when the steam system is shut down. Replace traps subject to freeze damage with self-draining types.



2 Install valves to facilitate testing. At each trap, install two valves in parallel. One is normally open and leads to the condensate return. The other valve leads to the atmosphere, and is normally closed. Periodic monitoring will indicate condensate removal rate and presence of live steam.

3 Establish appropriate steam trap diagnostics. Troubleshooting may involve visual, thermal, or sonic techniques. Visually observing trap discharge dumped temporarily to the atmosphere is the most straightforward and reliable method. Methods that rely on temperature differences across the trap to indicate proper operation can miss both small and large leaks. Sonic methods are very popular and employ hollow pipes, stethoscopes, or sonic detectors placed on the trap. For each type of trap tested, maintenance personnel must distinguish between sounds associated with proper operation and failure.

Loss @ 100 psi, 3/8 "	475 lbs/hour
Cost of steam production	\$15 per 1000 lbs
Operating time	8000 hours/year
Cost of leaking trap	\$57,000 per year

Type of Trap	Maintenance Characteristics
Float-type mechanical traps	Float-operated valve located under water level prevents steam escape. Does not vent air and gas, and usually has integral thermostatic vent.
Inverted bucket mechanical trap	Fairly resistant to water hammer and steam leaks. Prone to freezing. Vents only limited amounts of air.
Bellows actuated thermostatic trap	Prone to water hammer damage.
Bimetallic thermostatic trap	Not vulnerable to water hammer.
Thermodynamic disk trap	Upon startup, air, gas, and cool condensate freely vented. Will dump live steam if cool air surrounds trap. May need insulation for proper operation.

4 Evaluate failures. If failure rates are high, dirt, corrosion, water hammering, and freezing are the usual causes.

5 Reduce debris in lines. Dirt can be from a variety of causes, and cannot always be avoided. Strainers help prevent dirt from damaging traps.

6 Reduce corrosion. Take immediate action to discover where corrosive elements are entering the system.

7 Reduce water hammering. Moving steam carries liquid condensate along with it at velocities of up to 160km/h (100 mph) until it suddenly reaches a trap or valve, causing water hammer. Install traps at any low point or at intervals of 46m (150 feet) to reduce this physical shock.

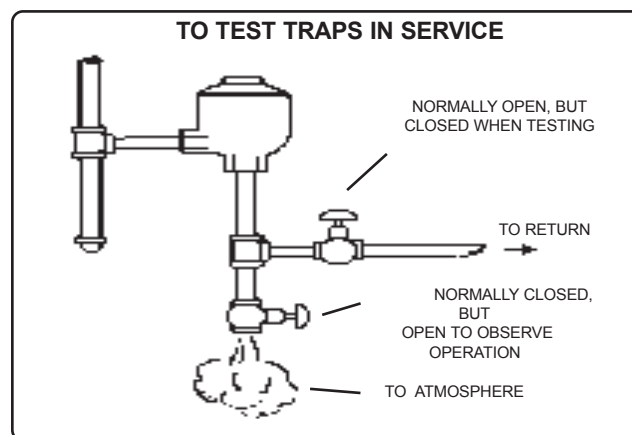
Checklist Indicating Possible

Steam Trap Failure

- Abnormally warm boiler room.
- Condensate receiver venting steam.
- Condensate pump water seal failing prematurely.
- Overheating or underheating in the conditioned space.
- Boiler operating pressure difficult to maintain.
- Vacuum in return lines difficult to maintain.
- Water hammer.
- Steam in condensate return lines.
- Higher than normal energy bill.
- Inlet and outlet lines to trap nearly the same temperature.

8 Insulate traps. Convective and radiative heat losses from steam traps can cost hundreds of dollars, depending on the size and temperatures of the trap and surrounding air.

9 When visually checking trap operation, consider the pressure in the condensate return line. If condensate pressure is less than atmospheric pressure, the visual method is useless.



References

Dyer, David, Glennon Maples and Timothy Maxwell, *Steam Efficiency Improvement*, Boiler Efficiency Institute, Auburn University, Auburn, AL, 1987.

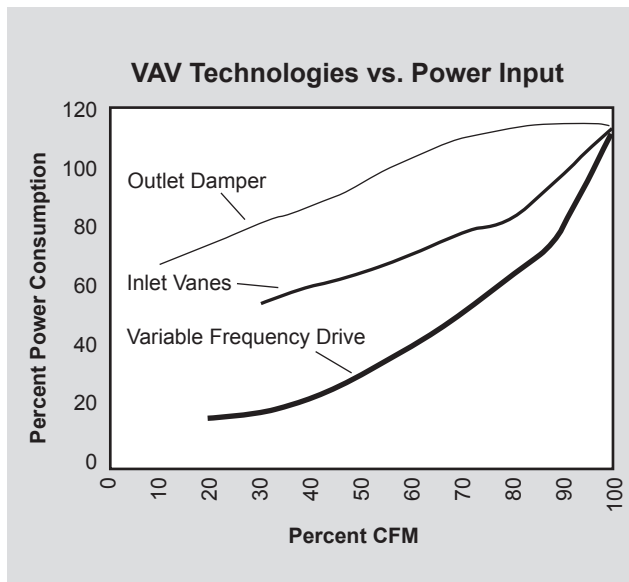
Contacts

For seminars concerning steam traps, contact the FEMP Help Desk at (800) DOE-EREC.

Fan motors in air handlers can account for 20% or more of energy usage in a commercial building. Energy costs of air distribution systems can be significantly decreased by: (1) converting constant-volume systems to variable-air-volume systems (VAV) or (2) increasing the efficiency of existing VAV systems.

Action Moment

Good candidates for VAV conversion are constant-volume (CV) systems with dual-ducts or terminal reheat that use backward-inclined or airfoil fans.



On existing VAV systems, convert airflow control from inlet vanes or outlet dampers to variable frequency drives (VFDs). Notice on the graph above how energy consumption using VFDs is far lower than using outlet dampers or inlet vanes.



Technical Information

Several strategies for making VAV systems more efficient while still providing necessary ventilation are outlined below.

1 Convert constant-volume (CV) systems to variable-air-volume (VAV). The airflow in many duct systems is fixed. A constant volume of air is

heated or cooled regardless of the actual volumes needed to satisfy the temperature and humidity requirements of the space. The inefficiency of dual-duct and terminal reheat CV systems can be virtually eliminated by converting the system to deliver only the volume of air needed for conditioning the actual load.

2 Install a variable frequency drive (VFD) on fan motors to achieve speed control. Electronically controlling the fan motor's speed and torque provides an efficient way to continually match fan speed with changing building load conditions. Rather than running at full speed 90% to 95% of the time, a fan motor controlled by a VFD can operate at speeds of 80% or less. Notice on the graph on the next page how this reduces energy consumption of fan motors by 50%.

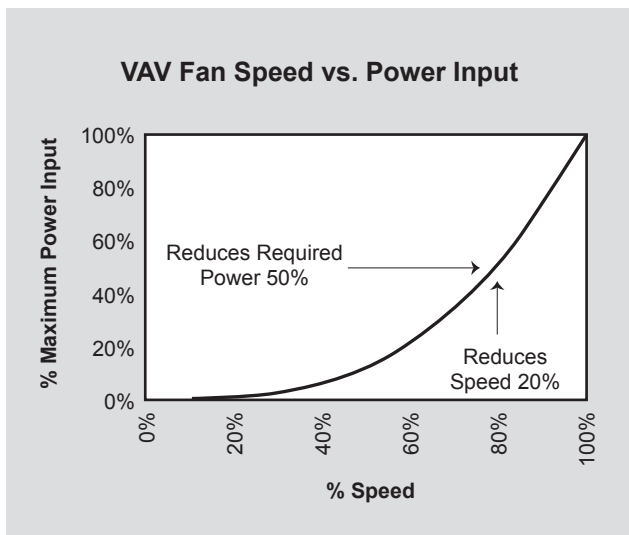
3 Match fan speed to the reduced building loads. The EPA found 58% of the buildings they surveyed had fans oversized more than 10%, with the oversizing averaging 72%. Two steps to match fan speed to the building load are:

- **Assess fan performance** by taking measurements on a peak cooling day. If vanes and dampers are closed more than 20%, the fan RPM may be reduced.
- **Lower fan speed** by increasing the fan pulley diameter or reducing the motor pulley diameter. A 10% speed reduction will lower energy usage by 27%. A 20% speed reduction saves approximately half the energy.

4 Replace existing motors with properly sized energy-efficient models. Compared to standard motors of equivalent-rated horsepower, high-efficiency motors use 3% to 8% less energy. They also run cooler, are more reliable, and usually have longer warranties.



Be certain that proper ventilation and humidity control is provided by VAV systems, even when heating and cooling needs are low. Space ventilation can be reduced below acceptable limits



during mild weather if fans are allowed to respond only to space temperature requirements. This is a very important indoor air quality issue.



An energy-efficient motor has less phase lag and therefore runs faster. Unless pulley sizes are adjusted, some of the savings will be lost by operating the fan at higher RPMs.

Experience has shown that VFDs installed on existing VAV systems using vane or damper airflow controls will save 30% to 60% of fan motor energy and reduce electrical demand from fans by 27%. Simple paybacks of appropriate retrofits average 2.5 years.

Facility managers can evaluate the benefits of reducing equipment sizes of fan systems in facilities by running EPA's QuikFan software. The software is available to Green Lights and Energy Star Building Partners.

Reference

Environmental Protection Agency, *Variable Air Volume Systems: Maximum Energy Efficiency and Profits*, (430-R-95-002), 1995.

The Ideal Fan Laws

The three ideal fan laws relating fan speed to capacity, static pressure, and horsepower are:

- (1) $CFM_1/CFM_2 = RPM_1/RPM_2$ volume flow rate (CFM) is proportional to the speed (RPM);
- (2) $SP_1/SP_2 = (RPM_1/RPM_2)^2$ static pressure (SP) varies as the square of speed; and,
- (3) $BHP_1/BHP_2 = (RPM_1/RPM_2)^3$ brake horsepower (BHP) varies as the cube of speed.

For example, assume a fan moves 30,000 CFM of air, develops a static pressure of 2" w.g, rotates at 400 RPM, and draws 12 BHP. The ideal fan laws can be used to find the capacity, pressure, and horsepower if the speed is increased to 500 RPM.

- (1) Capacity: $CFM_2 = CFM_1 * RPM_2 / RPM_1 = 30,000 * (500/400) = 37,500$ CFM
- (2) Static pressure: $SP_2 = SP_1 * (RPM_2 / RPM_1)^2 = 2 * (500/400)^2 = 3.1$ " w.g.
- (3) Brake horsepower: $BHP_2 = BHP_1 * (RPM_2 / RPM_1)^3 = 12 * (500/400)^3 = 23.4$ BHP

Caution should be used when applying the ideal fan laws to actual conditions. Note that the ideal fan laws apply only when all flow conditions are similar.

In large Federal facilities, the equipment used to produce chilled water for HVAC systems can account for up to 35% of a facility's electrical energy use. If replacement is determined to have the best life-cycle cost, there are some excellent new chillers on the market. The most efficient chillers currently available operate at efficiencies of 0.50 kilowatts per ton (kW/ton), a savings of 0.15 to 0.30 kW/ton over existing equipment. When considering chiller types and manufacturers, part-load efficiencies must also be compared.

Action Moment

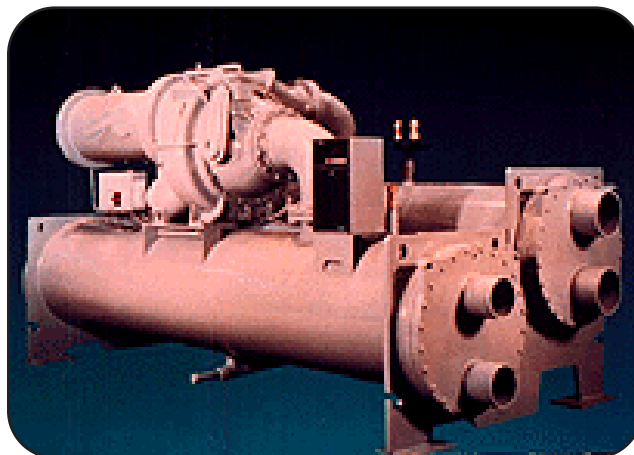
Consider chiller replacement where existing equipment is more than ten years old and the life-cycle cost analysis confirms that retrofit is worthwhile. New chillers can be 30% to 40% more efficient than existing equipment. Consider integrating other energy conservation measures along with a chiller retrofit. For example, using more efficient lighting may reduce cooling loads, allowing a smaller replacement chiller. Be aware that there can be lead times of six months or more for delivery of new chillers.



Technical Information

Electric chillers use a vapor compression refrigerant cycle to transfer heat. Basic components of an electric chiller are: electric motor, refrigerant compressor, condenser, evaporator, expansion device, and controls. Both the heat rejection system and building distribution loop can use water or air as the working fluid. Wet-condensers usually incorporate one or several cooling towers. Evaporative condensers can be used in some climates. Air-cooled condensers incorporate one or more fans to cool refrigerant coils, and are common on smaller packaged rooftop units. Air-cooled condensers may also be located remotely from the chillers.

1 The refrigerant issues currently facing facility managers arise from concerns about protection of the ozone layer and the buildup of greenhouse gases in the atmosphere. The CFC refrigerants traditionally used in most large chillers were



Some manufacturers have completely re-engineered their new chillers to operate at high efficiencies with HCFC and HFC refrigerants.

phased out of production on January 1, 1996 to protect the ozone layer. CFC chillers still in service must be: (1) serviced with stockpiled refrigerants or refrigerants recovered from retired equipment; or (2) chillers must be converted to HCFC-123 (for the CFC-11 chillers) or HFC-134a (for the CFC-12 chillers); or (3) the chillers must be replaced with new chillers using EPA-approved refrigerants.

2 All refrigerants listed for chillers by the EPA Strategic New Alternatives Program (SNAP) are acceptable. These include HCFC-22, HCFC-123, HFC-134a, and ammonia for vapor-compression chillers. HCFC-22 will be phased out in the year 2020. HCFC-123 will be phased out in the year 2030. Chlorine-free refrigerants such as HFC-134a and water/lithium-bromide mixtures, are not currently listed for phaseout.

3 A chiller operating with a CFC refrigerant is not directly damaging to the ozone, provided the refrigerant is totally contained during the chiller's operational life and the refrigerant is recovered upon retirement. In fact, indirect global damage from releases at power plants will be minimized by using highly efficient chillers no matter what fully-contained refrigerant a chiller has used.

4 Many older chillers contain refrigerants that are no longer produced, giving facility managers an additional incentive to replace equipment. Some new chillers have

been completely re-engineered to use refrigerants that are not currently scheduled for phaseout. Proper refrigerant handling is a requirement for any of the options relating to chillers operating with CFC refrigerants. The three options are containment, conversion, or replacement.

5 Containing refrigerant in existing chillers is possible with retrofit devices that ensure that refrigerant leakage is eliminated. Containment assumes that phased-out refrigerants will continue to be available by recovering refrigerants from retired systems.

6 Converting chillers to use alternative refrigerants will lower their performance and capacity. The capacity loss may not be a problem with converted units, since existing units may have been oversized when originally installed, and there may have been load reduction through energy conservation activities.

7 Replacing existing chillers should be considered as a method for complying with refrigerant phaseout requirements provided the life-cycle cost analysis determines replacement to be cost-effective. Absorption chillers use water/lithium bromide or ammonia/water mixtures, and use an energy source such as natural gas or steam to generate chilled water. DOE and GSA have established a Basic Ordering Agreement (BOA) to greatly simplify procurement of energy-efficient water-cooled chillers.

8 Electric chiller classification is based on the type of compressor they contain. Common types of compressors for electric chillers include: cen-

EPA Comparison of Refrigerant Alternatives				
Criteria	HCFC-123	HCFC-22	HFC-134a	Ammonia
Ozone Depletion Potential	0.016	0.05	0	0
Global Warming Potential	85	1,500	1,200	0
Ideal kW/ton	0.46	0.5	0.52	0.48
Occupational Risks	low	low	low	low
Flammable	no	no	no	yes

trifugal, screw, and reciprocating. The scroll compressor is another type frequently used for smaller applications of 20 to 60 tons. Hydraulic compressors are a fifth type still under development.



Chiller improvements in recent years include units completely re-engineered for use with new HCFC and HFC refrigerants. New machines have full-load efficiencies down to 0.50 kW/ton in the 170 to 2,300 ton range. Some have built-in refrigerant containment, are designed to leak no more than 0.1% refrigerant per year, and do not require purging.

Other improvements include larger heat transfer surfaces, microprocessor controls for chiller optimization, high efficiency motors, variable frequency drives, and optional automatic tube-cleaning systems. To facilitate replacement, new equipment is available from all manufacturers which can be unbolted for passage through conventional doors into equipment rooms. Many positive-pressure chillers are approximately one-third smaller than negative-pressure chillers of similar capacity.

1 Thermal energy storage may be added when replacing chillers, and may enable the use of smaller chillers. Operating costs may be reduced by lowering electrical demand charges and by using cheaper, off-peak electricity. Thermal storage systems commonly use one of three thermal storage media: water, eutectic salts, or ice. These systems can store 1 ton-hour of cooling per approximately 0.33, 0.07, and 0.04 m³ (11.4, 2.5 and 1.5 ft³), respectively.

2 Multiple chiller operations may be made more efficient by using unequally-sized units. With this configuration, the smallest chiller can efficiently meet light loads. The other chillers are staged to meet higher loads after the lead chiller is operating near full capacity. If chillers operate frequently at part-load conditions, it may be cost effective to replace a large chiller with multiple chillers staged to meet varying loads.

3 Double-bundle chillers have two possible pathways for rejecting condenser heat. One pathway is a conventional cooling tower. The other pathway is heat recovery for space heating or service water heating. Candidates for these chillers are facilities in cold climates with substantial hours of simultaneous cooling and heating demands. Retrofitting existing water heating may be difficult due to the low temperature rise available from the heat recovery loop.

4 Steam or hot water absorption chillers use mixtures of water/ lithium-bromide or ammonia/water that are heated with steam or hot water to provide the driving force for cooling. This eliminates global environmental concerns about refrigerants used in vapor-compression chillers. Double-effect absorption chillers are significantly more efficient than single-effect machines.

5 Specifying and procuring chillers should include load reduction efforts, equipment sizing, and good engineering. Proper sizing is important in order to save on both initial costs and operating costs. Building loads often decrease over time as a result of conservation measures, so replacing a chiller should be accomplished only after recalculating building loads. Published standards such as ASHRAE 90.1 and DOE standards provide guidance for specifying equipment. Procuring energy-efficient water-cooled electric chillers has been made considerably easier for facility managers. DOE and GSA have developed a Basic Ordering Agreement (BOA) that specifies desired equipment parameters.



Several alterations may be considered to make existing chiller systems more energy efficient. Careful engineering is required before implementing any of these opportunities to determine the practicality and economic feasibility.

1 Variable frequency drives (VFD) provide an efficient method of reducing the capacity of centrifugal chillers. Note that VFD drives are typically installed at the factory. Savings can be significant, provided: (1) loads are light for many hours per year; (2) the climate does not have a constant high wet-bulb temperature; and, (3) the condenser water temperature can be reset higher under low part-load conditions. VFDs are usually needed on only one chiller per installation, because the fixed-speed chillers can be staged for base load, with the VFD chiller varying capacity according to swings in the load.

2 Chiller bypass systems can be retrofitted into central plants enabling waterside economizers to cool spaces with chillers off-line. In these systems, cooling tower water provides chilled water either directly with filtered cooling tower water or indirectly with a heat exchanger. These systems are applicable when: (1) chilled water is required many hours per year; (2) outdoor temperatures are below 13°C (55°F); (3) economizer cycles cannot be used; and, (4) cooling loads below 13°C (55°F) do not exceed 35% to 50% of design full loads.

3 Other conservation measures to consider when looking at the chiller system are:

- Separate primary and secondary pumps
- High efficiency pumps and motors



Overall HVAC system efficiency should be considered when altering chiller settings. The complex interrelationships of chiller system components can make it difficult for operators to understand the effects of their actions on all components of the systems. For example, one way to im-

prove chiller efficiency is to decrease condensing water temperature. However, this requires additional cooling water pumping and cooling tower operation that may actually increase total operating costs.

Increasing chilled water temperature to save energy may unacceptably reduce humidity removal in humid climates.



Rooftop retrofits. Many Federal buildings are cooled via roof-mounted direct-expansion (DX) air conditioners. Where many of the individual rooftop DX units that cool a building are old and inefficient, it may be possible to retrofit them to use a single high-efficiency chiller (18 and greater EER). In the retrofit process, the existing evaporator coils are adapted to use glycol that is cooled by the chiller. Ice storage may be incorporated as part of the rooftop retrofit. The chiller can be operated at night to make ice, which would provide or supplement cooling during the day. This retrofit system provides an efficient means of reducing on-peak electric demand, previously discussed on page 22 under Thermal Storage. FEMP estimates a very high savings potential from this system. If all rooftop DX systems used in Federal buildings were replaced by chillers, more than 50% of the electricity used by rooftop units could be saved. Available space for the chiller and, if included, the ice storage, is a consideration for this type of retrofit.

References

Building Operators and Managers Association, "EPA Guide to CFC Planning," July, 1993.

General Services Administration, Facility Management Division, *Energy Management: A Program to Reduce Cost and Protect the Environment*, Washington, DC, 1994.

Electric Power Research Institute, *Electric Chiller Handbook*, (TR-105951s), Pleasant Hill, CA, 1995. (510) 934-4212

Fryer, Lynn, *Electric Chiller Buyer's Guide: Water-Cooled Centrifugal and Screw Chillers*, Technical Manual, E-Source, Inc., Boulder, CO, 1995. (303) 440-8500

Space Cooling Manual, E-Source, Inc., Boulder, CO, 1995. (303) 440-8500

Contacts

For more information about the Basic Ordering Agreement (BOA) for energy-efficient water-cooled chillers, contact the General Services Administration at (817) 978-2929.

New HVAC technologies can help facility managers achieve the goals of lowering energy costs, being more environmentally friendly, and enhancing indoor environmental quality. Information is provided here to help facility managers consider these new technologies. New technologies may only be available from one manufacturer and their energy savings claims may not be widely supported. *Federal Technology Alerts* provide additional information on some new HVAC technologies.

Action Moment

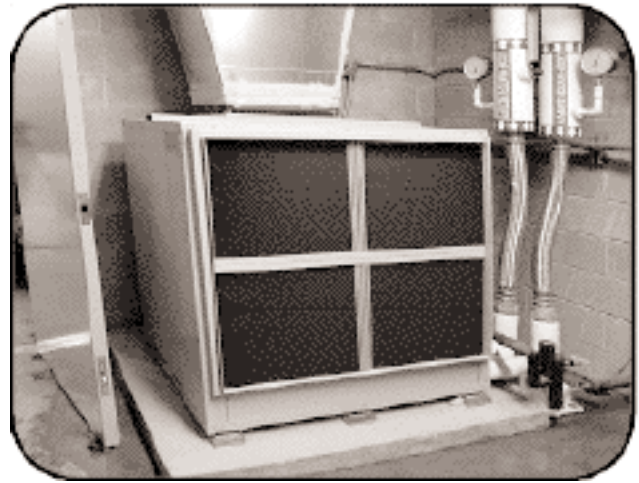
Where indoor humidity is either too high or is controlled with reheat systems, consider adding desiccants, heat pipes, and subcool systems. Where electrical power demand costs are high, consider gas absorption cooling or geothermal heat pumps.



Ground-Source Heat Pumps

Ground-source heat pumps use the earth's mass as a thermal reservoir—a heat sink during the summer and heat source during the winter. Ground source systems are generally more efficient than air-source systems, provided water pumping costs are minimal. Although both initial cost and maintenance cost are higher than for air-source systems, the advantages warrant their consideration. Ground-source heat pumps come in two basic types: (1) closed systems using buried plastic pipe with an antifreeze solution as the heat transfer medium; and (2) open systems that pump groundwater for use in heat exchangers. Several configurations are available for different applications.

Large tonnage ground source heat pumps often consist of multiple water-source heat pumps ranging in size from 1 to 15 tons. These unitary heat pumps are typically connected to a common ground-coupled water loop. With this arrangement, each small heat pump is responsible for an individual control zone, yet each can take advantage of the stable heat source and heat sink temperatures of the ground-coupled loop. The individual



Multiple water-source heat pumps can be connected to a common ground-coupled water loop.

water-source heat pumps are factory charged, usually eliminating the need for field adjustment of the refrigerant amounts. Variations in the basic configuration of the ground loops that can lower initial costs or reduce operating costs include supplementing with a cooling tower or solar panels, or adding a hot water recovery/desuperheater system.

1 Cooling Tower Supplemented Systems can reduce the total size of the ground loop required to meet the cooling demand. A cooling tower is added to the ground-coupled loop by means of a heat exchanger.

2 Solar Assisted Systems can help supplement the heating in northern climates. This strategy adds solar panels designed to heat water to the ground-coupled loop, thereby reducing the size needed for heating.

3 Hot Water Recovery/Desuperheating is an option to provide hot water that is available for most heat pump systems. With the heat pump operating in cooling mode, hot-water recovery increases the operating efficiency of the system, and produces essentially free hot water. With the heat pump in heating mode, hot water is produced at a lower cost compared to other technologies.



Small earth-coupled geothermal systems that use sealed pipes buried horizontally or vertically may be used for space heating or hydronic ice melting in critical high-traffic areas.

Use of heat pump systems is complicated by the need to keep heat exchangers clean while avoiding chemical discharge into surface or groundwater. After use for heat exchange, inject groundwater into the source aquifer.

Consider ground-source heat pumps to reduce demand charges under severe weather conditions. Since ground temperature does not get as hot or cold as the air temperature, the ground-source heat pump has the potential to operate more efficiently when heating in extremely cold weather or cooling in extremely hot weather. See the *Federal Technology Alert* on this subject.



Transpired Air Collectors

A transpired air collector heats up ventilation makeup air passively via a large solar collector. These collectors usually consist of south-facing building facades that have been constructed to include air channels under the outer building skin. Makeup air is drawn through the collector before it enters the building. Fort Carson uses a transpired air collector wall to warm outside fresh air before it enters an aircraft hanger. These systems preheat intake air by 17°C to 28°C (30°F to 50°F). It has been reported that these systems can reduce annual heating cost by \$1 to \$3 per square foot of collector wall, depending on fuel type, and can reduce demand on boiler systems.



Natural Gas Engine-Driven Cooling

An engine-driven cooling system is similar to a conventional electric cooling system, except the compressor is driven by a natural gas engine rather than an electric motor. Configurations include chillers, packaged direct expansion units, and heat pumps in sizes from 3 tons to 4,000 tons. Engine-driven systems are variable speed, have higher part-load efficiencies, generate high-temperature waste heat, and may save operating costs.

Consider engine-driven natural gas cooling to reduce electrical peak demand or to take advantage of low cost fuel.



Natural Gas Absorption Cooling

Gas absorption units use "thermal compressors" that circulate water or ammonia rather than mechanical compressors that use conventional refrigerants. Heat drives the process. Direct-fired machines use integral gas burners, and indirect-fired machines are powered by steam, hot water, or waste heat. Double-effect units that contain a second generator and condenser are more efficient than single-effect machines. Sizes range from 3 to 1700 tons.

Consider absorption cooling where electric power is expensive, natural gas is relatively cheap, or waste heat is adequate to supplement the process. Natural gas absorption machines are minimal contributors to ozone depletion because they do not contain CFC refrigerants.



Cooling Equipment With Enhanced Dehumidification

Reducing indoor humidity is a prime factor in discouraging microbiological growth in the indoor environment. Several technologies applicable to direct-expansion (DX) cooling can efficiently remove moisture.

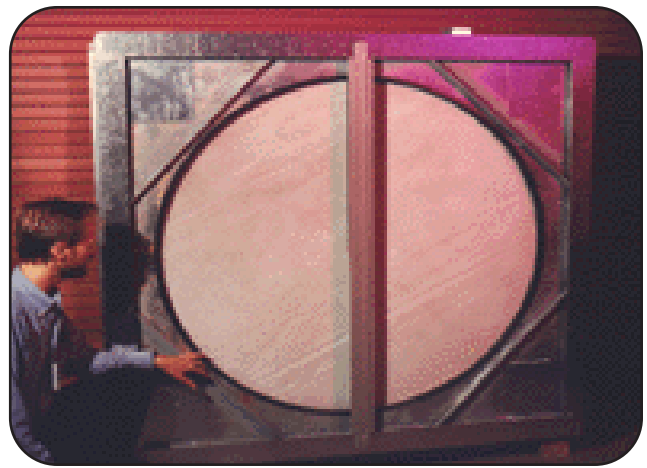
Heat pipes enable DX coils to remove more moisture by precooling return air. Heat absorbed by the refrigerant in the heat pipe can then be returned to the over-cooled, dehumidified air coming out of the DX coils. The system is passive, eliminating the expense of active reheat systems. Somewhat more fan energy is required to maintain duct static pressure, as is the case when adding any new element to the ventilation system, but no additional pumps or compressors are required. Increased fan energy must be considered when calculating system energy savings. Energy savings up to 30% have been reported. At least one manufacturer builds a variable dehumidification system for DX equipment that pre-cools liquid refrigerant rather than the air stream.



Desiccant systems

1 A desiccant system converts humidity (latent load) into sensible heat, and then efficiently removes that energy through heat exchange with outdoor or exhaust air. If needed, further sensible cooling is provided by evaporative pads or cooling coils. In the case of coils, since they do not need to condense moisture, they are operated at a relatively high temperature where they are most efficient. Where humidity is a significant factor, and the load is calculated so that it is broken into its constituents of latent and sensible loads, a desiccant system can be used to handle the latent load, while the DX or chilled-water coils may be able to be substantially down-sized from that required in a traditional HVAC system.

2 Desiccant systems exchange heat and humidity between supply and regenerative air streams. The supply air stream, which may be outdoor air or HVAC return air, surrenders moisture to a desiccant. Rotating desiccant wheels or pumped liquid desiccants transport moisture to the regener-



Desiccant systems effectively remove moisture from buildings, and can be "regenerated" from heat supplied from waste heat sources.

ative air stream. Desiccant regeneration, or "drying out," is fueled by heat supplied from boilers, natural gas burners, electric heaters, or waste heat sources. Systems from 1,000 to 84,000 CFM are available.

3

Desiccant systems are most cost effective in applications with high latent loads, due to internal loads or humid climates. Also consider desiccant cooling systems to: eliminate reheat; efficiently treat large make-up airflows for improved indoor air quality; down-size ductwork in renovations; effectively extend chiller capacity by allowing coils to handle sensible load only, and thus run more efficiently; reduce electric peak demand; or use cogeneration energy.



Refrigerant Subcooling

1

Refrigerant subcooling systems save energy in air conditioners, heat pumps, or reciprocating, screw and scroll chillers by altering the vapor-compression refrigerant cycle. There are three types of refrigerant subcooling technologies being manufactured, each of which adds a heat exchanger on the liquid line after the condenser: (1) suction-line heat exchangers, which use the suction-line as a heat sink; (2) mechanical subcoolers that use a small, efficient, secondary vapor-compres-

sion system for subcooling; and (3) external heat sink subcoolers that used a mini-cooling tower or ground-source water loop as a heat sink. Subcoolers increase energy efficiency, cooling capacity, and expansion valve performance (decrease flash gas).

2 Applications for heat sink subcooling include: (1) where units are being replaced; (2) where building expansion is planned; or (3) where current capacity is inadequate. The best applications include climates that are hot year-round—1200 or more base-65°F (18°C) cooling degree days—and direct expansion systems. With external heat sink subcooling, condensing units and compressors should be down-sized, making the technology more appropriate where existing equipment is being replaced, where construction or expansion is planned, or where current cooling capacity is inadequate. Pacific Northwest National Laboratory's (PNL's) evaluation of sub-cooling in Federal facilities is contained in a *Federal Technology Alert* available from FEMP.



Liquid Refrigerant Pumping

1 Liquid refrigerant pumping (LRP) systems provide a simple means of increasing the cooling capacity and energy efficiency of new and existing refrigeration and HVAC systems. LRP systems consist, at minimum, of a small, reliable pump installed on the liquid refrigerant line after the condenser. The pump reduces compressor load by providing an efficient way to compensate for pressure drop through the liquid line and filter/dryer. This virtually eliminates flash gas (refrigerant boiling before the metering device) and allows the compressor discharge pressure setpoint to be lowered to obtain significant savings in cool weather.

2 LRP applications include direct-expansion equipment having metering devices to control refrigerant flow. Suitable equipment includes those with a thermostatic expansion valve, an evaporator pressure regulator, or a capillary tube—nearly all packaged or split air conditioning systems and reciprocating chillers. Savings result from lowered

condensing temperatures obtained by lowering the setpoint of the condenser head pressure. Potential candidates for application of LRP systems are: computer room air conditioners; refrigerated display cases; off-peak cold storage systems; refrigerated warehouses; process cooling applications; air conditioning systems and heat pumps. Pacific Northwest National Laboratory's evaluation of LRP in Federal facilities is contained in a *Federal Technology Alert* available from FEMP.

References

Department of Energy, Federal Energy Management Program, "Geothermal Heat Pumps," *Federal Technology Alert*, 1995

Department of Energy, Federal Energy Management Program, "Ground-Source Heat Pumps Applied To Commercial Facilities," *Federal Technology Alert*, 1995.

Department of Energy, Federal Energy Management Program, "Liquid Refrigerant Pumping," *Federal Technology Alert*, 1995.

Department of Energy, Federal Energy Management Program, "Polarized Refrigerant Oil Additive," *Federal Technology Alert*, 1995.

Department of Energy, Federal Energy Management Program, "Refrigerant Subcooling," *Federal Technology Alert*, 1995.

Department of Energy, Federal Energy Management Program, "Solar Ventilation Preheat," *Federal Technology Alert*, 1995.

American Gas Cooling Center, *Natural Gas Cooling Equipment Guide*, Arlington, VA, 1995.

Contacts

For information about all types of gas cooling equipment, contact the American Gas Cooling Center, Arlington, VA (703) 841-8409.

For the *Federal Technology Alerts* listed above, and other information about new HVAC technologies, contact the FEMP Help Desk at (800) DOE-EREC. The FEMP Home Page is at <http://www.eren.doe.gov/femp>.

International Ground-Source Heat Pump Association, (405) 744-5175.

Electric motors vary greatly in performance. The selection of energy-efficiency motors for HVAC equipment installed in renovation or new construction can result in greatly reduced energy consumption during their operational lifetimes. Recent developments in energy-efficient motors and motor controls provide excellent opportunities for facility managers to have long-term impacts on lowering energy consumption in Federal facilities.

Action Moment

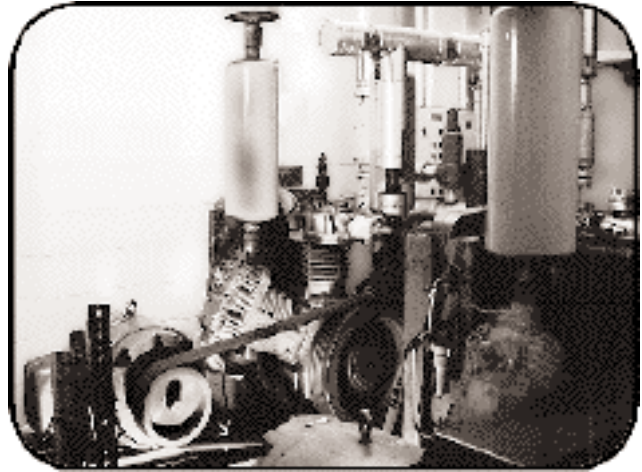
Facility managers should inventory all motors in their facilities, beginning with the largest and those with the longest run-times. This inventory enables facility managers to make informed choices about replacement either before or after motor failure. Field testing motors prior to failure enables the facility manager to properly size replacements to match the actual driven load. The software mentioned below can help with this inventory.



Technical Information

1 **The Motor Challenge Program** was developed by DOE to assist industrial customers in increasing their use of energy-efficient motor systems. Federal facility managers can also benefit from Motor Challenge through a special arrangement with FEMP, and receive technical assistance, training, software, and other materials.

2 **Motor Master Plus** is a PC-based software tool that helps inventory and select motors. A database of 12,000 new motors contained in the software includes horsepower, speed, enclosure type, manufacturer, model name, catalog number, voltage, nominal efficiencies at various loads, torque and current characteristics, power factor, warranty, and list price. The software allows users to simulate replacement scenarios to determine the lowest life cycle cost options for existing motors.



Motor Master Plus software can help facility managers prioritize the replacement of electric motors such as the motor on this compressor.

3 **The inventory features in Motor Master Plus** assist facility managers in tracking existing motors, including a motor's location and electrical measurements needed to determine loading. Developing an inventory is the first step in establishing a motor rewind/replacement policy that could result in significant reductions in operating expenses. Since motors are typically replaced or rewound when the motor fails, having an inventory will allow facility managers to quickly determine the most economical approach, and assist with proper selection. Inventoried motors also can be evaluated to prioritize replacement of functioning motors with premium-efficiency motors.



Turn off unneeded motors. Locate motors that operate needlessly, even for a portion of the time they are on. For example, there may be multiple HVAC circulation pumps operating when demand falls, cooling tower fans operating when target temperatures are met, ceiling fans on in unoccupied spaces, exhaust fans operating after ventilation needs are met, and escalators operating after closing.

Reduce motor system usage. The efficiency of mechanical systems affects the run-time of motors. For example, reducing solar load on a building will reduce the amount of time the air handler motors would need to operate. The table below contains a list of energy reducing strategies for motors.

Reduce Motor System Usage

- Reduce loads on HVAC systems.
 - Improve building shell.
 - Manage restorations better.
 - Improve HVAC conditions.
 - Check refrigerant charge.
- Reduce refrigeration loads
 - Improve insulation
 - Add strip curtains on doors
 - Calibrate control setpoints
 - Check refrigerant charge
- Check ventilation systems for excessive air
 - Re-sheave fan if air is excessive
 - Downsize motors if possible
- Improve compressed air systems
 - Locate and repair compressed air leaks
 - Check air tool fittings for physical damage
 - Turn off air to tools when not in use
- Repair duct leaks

Sizing motors is important. Do not assume an existing motor is properly sized for its load, especially when replacing motors. Many motors operate most efficiently at 75% to 85% of full load rating. Under-sizing or over-sizing reduces efficiency. For large motors, facility managers may want to seek professional help in determining the proper sizes and actual loadings of existing motors. There are several ways to estimate actual motor loading: the *kilowatt technique*, the *amperage ratio technique*, and the less reliable *slip technique*. All three are supported in the Motor Master Plus software.

Instead of rewinding small motors, consider replacement with an energy-efficient version. For larger motors, if motor rewinding offers the lowest life-cycle cost, select a rewind facility with high quality standards to ensure that motor efficiency is not adversely affected. For sizes of 10 hp or less, new motors are generally cheaper than rewinding. Most standard efficiency motors under 100 hp will be cost-effective to scrap when they fail, provided they have sufficient run-time and are replaced with energy-efficient models.

References

Department of Energy, *Energy-Efficient Electric Motor Handbook*, Revision 3, Washington, DC, 1993.

Hoslida, Robert K., "Electric Motor Do's and Don'ts," *Energy Engineering*, Vol 19, No 1, pp 6 - 24.

Nadel, Steven, et al., *Energy Efficient Motor Systems: A Handbook on Technology Programs, and Policy Opportunities*, American Council for an Energy-Efficient Economy, Washington, DC, 1991.

Contacts

FEMP is offering training to facility managers on the use of Motor Master Plus and other motor system management topics. Contact the FEMP Help Desk at (800) DOE-EREC, or the FEMP Home Page at <http://www.eren.doe.gov/femp>.

DOE's Motor Challenge Hotline at (800) 862-2086 provides information, software, and publications.

Motor Challenge Home Page at <http://www.motor.doe.gov> includes discussion forums, frequently asked questions, and application information.

Energy-efficient electric motors reduce energy losses through improved design, better materials, and improved manufacturing techniques. With proper installation, energy-efficient motors run cooler and consequently have higher service factors, longer bearing and insulation life, and less vibration. To be considered energy efficient, a motor must meet performance criteria published by the National Electrical Manufacturers Association (NEMA). Most manufacturers offer lines of motors that significantly exceed the NEMA-defined criteria.

Action Moment

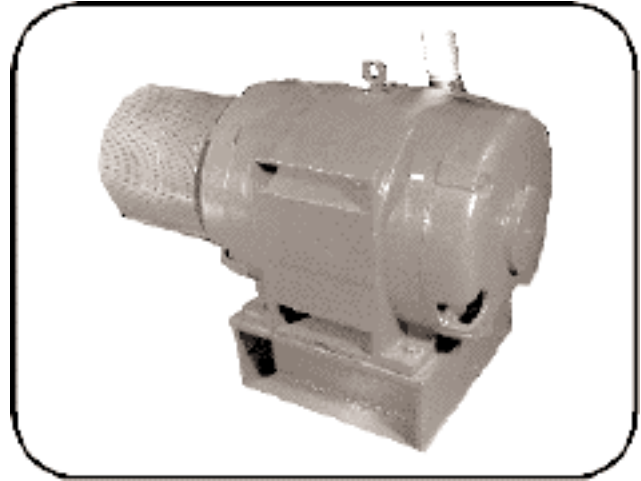
Facility managers should consider installing an energy-efficient motor when faced with a motor purchase decision. This includes adding an application, replacing a failed motor, or considering rewinding a failed motor. Replacing a functional motor may be justifiable solely on the electricity cost savings derived from an energy-efficient replacement. This is especially true if the motor runs continuously, electricity rates are high, the motor is significantly oversized for the application, or its nominal efficiency has been reduced by damage or previous rewinds. Priority opportunities are HVAC fan motors and circulation pumps.



Technical Information

1 In converting electrical energy into mechanical energy, motors incur losses in several ways: electrical losses, iron (core) losses, mechanical (friction and windage) losses, and stray losses dependent on design and manufacturing. Energy-efficient motors reduce losses by better design, materials, and manufacturing.

2 Manufacturers use many terms to describe their most efficient motors, including adjectives such as “high,” “super,” “premium,” and “extra.” These terms create confusion when comparing motors, so purchasers should always consult the *nominal efficiency rating* and the *minimum efficiency rating*. Nominal efficiency, an average effi-



Priority opportunities for motor replacement in Federal buildings include HVAC fan motors and pumps.

ciency of motors of duplicate design, is listed in manufacturer literature and in the Motor Master Plus software discussed in section 3.3. Even within the group of duplicate designs, there is some variation in actual efficiencies due to variations in motor materials and manufacturing. Minimum efficiency ratings can be used as the basis for the manufacturer's guarantee.

3 Table 12-10 of NEMA Standard MG-1 delineates efficiency “bins” that form the basis of the “NEMA nominal efficiency” ratings listed on nameplates. The bins provide ranges of efficiencies, such that actual nominal efficiencies are less than or equal to NEMA nominal efficiencies. For example, a motor with an actual nominal efficiency of 92.0 would have a nameplate efficiency listed as 91.7, since the NEMA bracket is 91.7, then 92.4. This standard applies only to A and B designs in the horsepower range of 1 to 500. The standard does not cover other sizes and designs, including C, D, vertical and specialty motors.

4 Energy-efficient motors tend to last longer, and may require less maintenance. At lower temperatures, bearing grease lasts longer, lengthening the required time between re-greasing. Lower temperatures translate to longer lasting insulation. Generally, motor life doubles for each 10°C reduction in operating temperature.



Inspect motors for misalignment or excessive vibration.

Inspect wires and connections on motors and incoming power for damage, corrosion, or looseness.

Check motor bearings, and, on single-phase motors, check for wear on internal switches.

Clean dirt and grease from the cooling fan and grill on totally enclosed, fan-cooled motors.

Select energy-efficient motors with a 1.15 service factor, and design for operation at 85% of the rated motor load.



Electrical power problems can affect the operation of energy-efficient motors. For example, plant personnel in one manufacturing operation blamed motor failures on the energy-efficient designs of their motors. However, further investigation revealed poor incoming power quality. Investigators suggested addressing the power quality instead of replacing the energy-efficient motors.

Speed control is crucial in some applications. In polyphase induction motors, slip is a measure of motor winding losses. The lower the slip, the higher the efficiency. Less slippage in energy efficient motors results in speeds about 1% faster than in standard counterparts.

Starting torque for efficient motors may be lower than for standard motors. Facility managers should be careful when applying efficient motors to high torque applications.



Facility managers can easily estimate operating savings of energy efficient motors for a particular application, given the efficiency at rated load, the partial load factor (PLF), the annual operating hours, and the electricity rate.

$$\$/\text{year} = \text{hp} \times \text{PLF} \times 0.746 \text{ kW/hp} \times \text{hours/year} \times \$/\text{kWh} / \text{efficiency}$$

Facility managers can also use Motor Challenge's Motor Master Plus software to estimate operating and energy savings. FEMP is offering training to facility managers on the use of Motor Master Plus software.

References

Department of Energy, *Energy-Efficient Electric Motor Selection Handbook*, 1993.

Electric Power Research Institute, *Energy-Efficient Motors and Controls*, Palo Alto, CA, 1987.

Nadel, Steven, et al., *Energy-Efficient Motor Systems: A Handbook on Technology, Programs, and Policy Opportunities*, American Council for an Energy-Efficient Economy, Washington, DC, 1991.

National Electric Manufacturers Association, *NEMA Standard MG-1*.

Skaer, Mark, "Energy-Efficient Motors: Are They Really More Efficient?" *Air Conditioning, Heating & Refrigeration News*, 1995.

Example of calculating savings from motor replacement. Determine the savings from replacing a 20 hp motor that operates 80% loaded (PLF) for 8,760 hours per year where electricity costs 5.5 cents per kilowatt-hour. Assume efficiencies are 0.88 and 0.92 for standard and energy-efficient motors, respectively. Notice that this does not include savings from reducing electrical power demand.

Standard motor:	20 hp x 0.80 x 0.746 kW/hp x 8760 hr/yr x \$0.055 per kWh / .88= \$6535 per year
Efficient motor:	20 hp x 0.80 x 0.746 kW/hp x 8760 hr/yr x \$0.055 per kWh / .92= \$6251 per year
Savings:	\$6535 - \$6251 = \$ 284 per year

Variable frequency drives (VFDs), a type of variable speed drive, are motor controllers that vary the speed of squirrel cage induction motors. VFDs save substantial energy when applied to variable-torque loads, and result in reductions in electricity bills in most facilities. These energy savings are possible with variable-torque loads, such as fans and pumps, because torque varies as the square of speed, and horsepower varies as the cube of speed. For example, if fan speed is reduced by 20%, motor horsepower (and energy consumption) is reduced by 50%. VFDs generate variable voltage and frequency output in the proper volts/hertz ratio for the motors from the fixed utility-supplied power. VFDs can be retrofitted into existing motor systems, and can operate both standard and high-efficiency motors ranging in size from 1/3 hp to several thousand hp. Unlike mechanical or hydraulic motor controllers, they can be located remotely and do not require mechanical coupling between the motor and the load. This simplifies installation and alignment of motor systems.

Action Moment

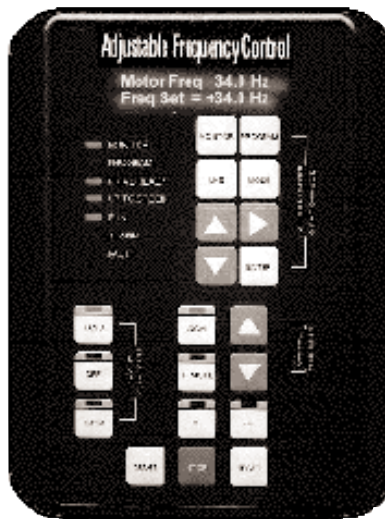
Variable-flow applications where throttling or bypass devices are used to modulate flow are good candidates for VFDs. These include centrifugal fans, pumps (centrifugal, propeller, turbine), agitators, and axial compressors. If HVAC fans have inlet vanes or outlet dampers to throttle full air output installed in variable-air-volume systems, these dampers or vanes typically can be removed or disabled and retrofitted with VFDs. Circulation pumps for chilled water often have throttling or bypass valves that can be retrofitted with VFDs.



Technical Information

Three major VFD designs are commonly used: pulse width modulation (PWM), current source inverter (CSI), and variable voltage inverter (VVI).

A fourth type, the flux vector PWM drive, is gaining popularity but is considered too expensive and sophisticated for normal applications. Knowing the characteristics of the load is critical for evaluating the advantages and disadvantages of each available technology.



1 Pulse width modulation (PWM) is the dominant VFD design in the 1/2 HP to 500 HP range because of its reliability, affordability and availability. PWM outputs emulate sinusoidal power waves by varying the width of pulses in each half cycle. Advantages of PWMs are low harmonic motor heating, excellent input displacement power factor, high efficiencies at 92% to 96%, and ability to control multiple motor systems with a single drive.

2 Current source inverter (CSI) designs are quite reliable due to their inherent current-limiting characteristics and simple circuitry. CSIs have regenerative power capabilities, meaning that CSI drives can reverse the power flow back from the motor through the drive. However, CSIs “reflect” large amounts of power harmonics back to the source, have poor input power factors, and produce jerky motor operations (cogging) at very low speeds. CSIs are typically used for large (over 300 hp) induction and synchronous motors.

3 Voltage source inverter (VSI) designs are similar to CSI designs, but VSIs generate variable-frequency outputs to motors by regulating voltage rather than current. Harmonics, power factor, and cogging at low frequencies can be problems.



The best applications for VFDs are large motors that can operate for many hours each year at reduced speeds. Some opportunities common in facilities include the following.

1 Variable-air-volume HVAC fans. Air flow in older VAV systems is usually controlled by opening and closing dampers or inlet vanes. Because the systems often operate at low air flow, large energy savings are possible by conversion to VFDs. VFDs vary motor speed in order to match fan output to varying HVAC loads.

2 Cooling tower fans. Cooling towers may be good candidates for VFDs because motors are large, fans can operate for long periods of time, and loads can vary both seasonally and diurnally.

3 Circulating water pumps for chillers and boilers. Pumping systems can be made variable by sequencing fixed-speed pumps and a single variable speed pump. This will save the cost of installing VFDs on each pump.

4 Special industrial applications such as grinding and materials handling where precise speed control is required. The economics depend on the size and run-time of the motors involved.



VFDs should be properly installed to avoid damage to their electronics. This includes proper grounding, mounting, connection, voltage, and cooling.

1 Installing VFDs intended for wall mounting as free standing units will interfere with the “chimney effect” cooling of the heat sink. Always install wall-mounted units against a smooth, flat, vertical surface or install a piece of plywood or sheet metal to create the required cooling channels.

2 Ensure that the power voltage supplied to VFDs is stable within plus or minus 10% to prevent tripping faults.

3 Motors operating at low speeds can suffer from reduced cooling. For maximum motor protection on motors to be run at low speeds, install thermal sensors that interlock with the VFD control circuit. Standard motor protection responds only to over-current conditions.

4 Speed control wiring, which is often 4 mA to 20mA or 0 VDC to 5 VDC, should be separated from other wiring to avoid erratic behavior. Parallel runs of 115V and 24V control wiring may cause problems.



Precautions for specifying, installing and operating VFDs are numerous. Improper installation and start-up accounts for 50% of VFD failures.

1 Use the VFD start-up sheet to guide the initialization check prior to energizing the VFD for the first time.

2 Corrosive environments, humidity above 95%, ambient air temperatures exceeding 40°C (104°F), and conditions where condensation occurs may damage VFDs.

3 If a VFD is started when the load is already spinning, the VFD will try to pull the motor down to a low, soft-start frequency. This can result in high current and a trip unless special VFDs are used.

4 Switching from grid power to emergency power while the VFD is running is not possible with most types of VFDs. If power switching is anticipated, include this capability in the specification.

5 If electrical disconnects are located between the VFD and motor, interlock the run-permissive circuit to the disconnect.

6 If a motor always operates at rated load, a VFD will increase power use, due to electrical losses in the VFD.

7 Use "inverter duty" motors on new installations that will have VFDs.

References

Murphy, Howard G., “Power Quality Issues with Adjustable Frequency Drive - Coping with Power Loss and Voltage Transients,” *Iron and Steel Engineer*, February 1994.

Turkel, Solomon S., “Understanding Variable Speed Drives (parts 1 to 6),” *Electrical Construction and Maintenance*, February to July 1995.

Induction motors, magnetic ballasts, and transformers require two types of power to operate. Active power (also called true or real power) produces work or heat, is used by all electrical devices, and is expressed in kilowatts (kW). Reactive power is used by inductive devices to generate magnetic fields. It does not perform useful work, and is expressed as kVARs (kilovolt-amps reactive). Total power, or apparent power, is the vector sum of active and reactive power and is expressed in kVA (kilovolt-amps). A power factor is the ratio of active power to total power and quantifies the portion of power used by a facility that does electrically useful work. Power companies generally charge an additional fee to facilities having power factors less than 85% to 95% in order to capture costs not reflected by the electric energy (kWh) meter. Improving the power factor can increase current-carrying capacity, improve voltage to equipment, reduce power losses, and lower electric bills.

Action Moment

Improve power factors if: (1) power factors are below 90% to 95% and penalties charged by the electrical utility are high; (2) electrical problems within the facility can be eliminated by improving the power factor; or (3) rewiring with large wire for capacity needs can be deferred.



Technical Information

Electric motors are large contributors to poor power factors because many generally operate under light loads. Lower power factors do not necessarily increase peak kVA demand because of the reduction in load. For example, the power factor of an electric motor is lowest when the motor is lightly loaded. This occurs when both its power draw and contribution to the electrical peak demand is the least.

Power factor correction capacitors are designed to provide the reactive current needed by inductive loads. Capacitors may be installed to improve the



Power factor monitoring can help increase current-carrying capacity and reduce the cost of electrical power.

power factor of a single load or an entire power system, and come in sizes from 1 to 600 kVARs.

Automatic power factor correcting equipment switches banks of capacitors on- and off-line depending on the power factor. These may provide good solutions where reactive loads vary in magnitude over time.

Locate capacitors upstream of motor controllers unless full-voltage, non-reversing, across-the-line starters are used.



Replace standard motors with energy-efficient motors with high power factor ratings.

Beware that even high-efficiency motors will have poor power factors under low load conditions. Note that efficiency is more important than power factor. Be sure not to sacrifice efficiency for power factor. Avoid operating equipment above its rated voltage. Minimize operation of lightly loaded or idling motors.

Shut down a lightly-loaded motor in situations where a smaller, parallel motor can do the same job. For example, when chilled water demand drops, parallel pumps may be removed from service until loads increase.

Be aware that installing power factor correction capacitors on the load side of a motor overload protection device may require reducing the overload size. The capacitor manufacturer will have tables to assist in re-sizing.

Avoid over-sizing capacitors installed on the load side of motor controllers because they can discharge into the motor when the controller is turned off. Damaging voltages may occur if kVAR current exceeds motor no-load current.

The amount saved by improving the power factor will be the sum of several savings: reduction in power company fees; improved motor efficiency with proper voltage; and savings from released electrical capacity. Motor life may also be extended because motors with voltage that is too high or too low, run hotter, perform worse, and fail sooner.



Beware of applications where there are significant harmonics (VFDs and other non-linear loads). The harmonics can cause resonances with the capacitors and damage them. If harmonics exist, consider harmonic filters which also typically improve power factor.

Do not exceed manufacturer's recommendation on maximum capacitor size.

Power factor is less than one when energy is quickly stored and released in a piece of equipment so that the voltage and current are out of phase by the angle Θ .

$$\text{Power factor} = \frac{\text{watts}}{\text{volts} \times \text{amps}} = \cos \Theta$$

Additional power is not consumed but bigger wires and transformers are required to handle the additional amps needed by the load. Low power factor of large inductive loads, such as motors, can be improved by adding capacitors to the load. Current through a capacitor has the effect of cancelling out the lagging current.

References

Bonneville Power Administration, *Energy-Efficient Motor Selection Handbook*, (DE-B179-93-B08158), 1993.

Bonneville Power Administration, "Reducing Power Factor Cost," *Technology Update*, April 1991.

Morgan, Robert, "Improving Power Factor for Greater Efficiency," *Electrical Construction and Maintenance*, Sept and Nov 1994.